Chapter 6

RADIANT COOLING AND THE US MARKET

6.1 Introduction

The commitment of Western European countries to reduce their energy consumption translates into regulation that promotes energy efficient technologies. In particular, since cooling of non-residential buildings contributes significantly to electricity consumption and peak power demand, countries like Switzerland and Germany have adopted building standards that call for better building design, and for the replacement of traditional all-air systems with alternative, more efficient building conditioning systems. Information regarding the performance of radiant cooling systems indicates that they not only reduce the energy consumption for thermal distribution and for space conditioning, but also provide draft-free and noise-free cooling, reduce building space requirements, and might even have lower first-cost if the peak specific cooling loads are above 50 - 55 W/m^2. It is therefore not surprising that implementation of radiant cooling systems in Western European commercial buildings is currently under way.

The results of the parametric study conducted in this thesis suggest that installing radiant cooling systems instead of the traditional all-air systems in office buildings in the US can diminish the energy consumption and peak power demand due to space conditioning. Yet despite sustained efforts to promote energy efficiency in buildings, traditional all-air systems are still standard issue for new and retrofitted commercial buildings across the US. Furthermore, there is no evidence that the US air-conditioning market will adopt radiant cooling systems in the near future.

The absence of radiant cooling systems from the US market cannot be explained without examining the complex interaction of several technical, economic, social, and cultural factors. Instead of undertaking this ambitious task, this chapter limits itself to describing the realities of the US air-conditioning market, identifying some of the barriers that any “new” cooling technology must overcome before it can capture a share of this market, and reviewing some regulatory measures that would help alternative cooling technologies in general, and radiant cooling in particular, to overcome these barriers.

6.2 The Economic Theory of Increasing Returns

Conventional economic theory is built on the assumption of diminishing returns: economic actions generate negative feedbacks that lead to a predictable equilibrium for prices and market shares. Such feedbacks tend to stabilize the economy because any major changes will be offset by the very reactions they generate. The economy will therefore have a unique equilibrium point at any given time, a point that marks the “best outcome" possible for a given structure of the economy, the most efficient use and allocation of resources.

Arthur [1] shows that in reality only the parts of the economy that are resource-based (agriculture, bulk-goods production, mining, etc.) are still subject to diminishing returns. The parts of the economy that are knowledge-based are mostly subject to increasing returns. Products such as computers, pharmaceuticals, automobiles, aircraft, etc., are complicated to design and manufacture, and require large initial investments in research, development, and tooling. Once sales begin, however, incremental production is relatively cheap. Increased production brings additional benefits: producing more units means gaining more experience in the manufacturing process, and achieving greater understanding of how to manufacture additional units even cheaper. Moreover, experience gained with one product or technology can make it easier to produce new products incorporating similar or related technologies.

As opposed to diminishing returns, increasing returns magnify the effects of small economic shifts at the microeconomic level, and allow for many possible equilibrium points at the macroeconomic level. When one economic outcome is realized from the many possible alternatives, there is no guarantee that *that* particular outcome is also "the best". Furthermore, once random economic events select a particular path, the choice may become locked-in regardless of the advantages of the alternatives. If one product in the marketplace gets ahead "by chance", positive feedback often helps it stay ahead and increase its lead. Predictably, shared markets are no longer guaranteed in the parts of the economy governed by increasing returns. Instead of being offered a chance to capture a share of the market, a firm or technology trying to penetrate a locked-in market will be driven to failure, or will be taken over by an already-established firm.

Although the US air-conditioning industry is not knowledge-based, it presents certain similarities to the automobile industry: both are capital-intensive, both market goods that are relatively complicated to design and manufacture, and both require large initial investments in research, development, and tooling. The difficulties generally encountered by "new" space cooling technologies attempting to capture a share of the US air-conditioning market may signal that the economy of the air-conditioning market is subject to increasing returns, and that traditional HVAC systems relying on compressor-driven chillers have locked-in, or almost locked-in the market.

Feustel and collaborators [2] state that compressor-driven chillers are currently "the easy way to supply cooling". To support this statement, they bring the following arguments:

(1) under the current building standards, matching a cooling unit to a building can be done rapidly by using rule-of-thumb calculations;

(2) the first cost of compressor-driven chillers is relatively low;

(3) equipment, parts, and service are readily available;

(4) compressor-driven air-conditioning systems are mechanically reliable (they require little maintenance);

(5) they are available in a variety of sizes, satisfy any cooling requirements, and function even in extreme climatic conditions;

(6) air-conditioning systems relying on compressor-driven chillers are easy to control, and their reaction is relatively rapid.

By comparison, Feustel and collaborators find the following for existing "alternative" cooling technologies:[1]

(1) they require slightly more complicated calculations to design;

(2) their first cost is higher than that of the compressor-driven technology;

(3) equipment and parts are scarce, and expertise for installing and maintaining the systems is lacking;

(4) some "alternative" cooling technologies are unreliable in certain weather conditions, while others are incompatible with certain climates;

(5) most "alternative" cooling technologies have limited output and therefore cannot be employed in buildings with high cooling loads;

(6) most "alternative" cooling technologies require complex controls.

Radiant cooling systems have certain advantages when compared to the other alternative technologies;[2] however, they are still at a disadvantage when compared to all-air systems relying on compressor-driven chillers because:

(1) they require relatively complicated design calculations;

(2) although their first cost is comparable to that of all-air systems relying on compressor-driven chillers in Western Europe, there is very little data available about the cost of radiant cooling systems in the US - North American manufacturers do not disclose first cost information on the grounds that it is proprietary;

(3) although there are a few North American manufacturers who offer equipment and

1. Evaporative cooling, desiccant cooling and absorption cooling are some of the "alternative" cooling technologies currently available on the market. These technologies were developed to replace compressor-driven chillers in its role of cooling source for all-air HVAC systems.

2. Radiant cooling systems are "alternatives" to traditional all-air systems in that they substitute radiation for convection as main heat transfer mechanism, and water for air as heat transfer medium. The radiant cooling systems that have so far been installed in buildings still use chillers, albeit smaller ones, as main cooling source.

parts, expertise for installing and maintaining the systems is lacking;[1]

(4) assuming appropriate design and controls, they are reliable in any US climate, but there is an upper limit to the cooling loads that they can remove from a building.

The air-conditioning industry relying on compressor-driven chillers currently dominates the market largely due to its infrastructure. In 1993 about 70% of the US households had some type of compressor-driven air conditioner, and the Statistical Abstract of the US [3] indicates that the annual revenue from shipments of compressor-driven technology continues to increase.[2] By comparison, the infrastructure needed to support the alternative technologies, including radiant cooling, is not yet fully developed. Information regarding the number and type of buildings conditioned by systems relying on alternative technologies is scarce. The Statistical Abstract of the US does not even list data concerning the sales of “alternative” cooling technologies, or of radiant cooling systems.

6.3 The Regulatory Response

6.3.1 Theory

A sector of the economy governed by diminishing returns can be regulated fairly well by discouraging monopolies and maintaining open markets, but this type of regulation is not appropriate in a sector of the economy governed by increasing returns. Maintaining open markets is crucial for the achievement of technological advances in knowledge-based industries. However, because open markets allow dominant *technologies*, not *firms*, to gain monopoly-like status, policies that discourage monopolies cannot offer the regulation necessary in a sector governed by increasing returns. While addressing this problem, Arthur [1] identifies two types of regulation that are appropriate for a sector of the economy that is governed by increasing returns: policies supporting government subsidization, and policies encouraging joint ventures among small firms.

According to Arthur, government subsidization should be primarily directed towards the

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1. The Radiant Panel Association provides the following list of companies that market (heating and cooling) ceiling panels. According to The Radiant Panel Association, no “cooling only” panels are currently manufactured in North America.

    Aero Tech Manufacturing, Inc., Salt Lake City, Utah

    Engineered Air, Calgary, Alberta

    Frenger Canada Inc., Edmonton, Alberta

    Shelley Radiant Ceiling Co., Northfield, IL

    SUN•El Corporation, Latrobe, Pennsylvania

2. The revenue from shipments of compressor-driven equipment increased from \$6.6 billion in 1991 to \$7.9 billion in 1993.

protection of new industries, to allow them to capture foreign markets. However, as governments have a hard time justifying expenditures on industries that do not produce immediate profit, the adoption of such policies would probably encounter resistance. Moreover, if one country pursues such policies, others will retaliate in kind, and nobody can achieve any profits.

When stating the above, Arthur obviously forgets that he is proposing regulation directed at encouraging *technology development*. Even if "nobody achieves profits", fierce international competition can lead to significant technological advances for an industry, thus opening public access to improved products. Profits will be achieved during a subsequent stage, through the marketing or use of the improved products. The same can be stated at the national scale: if the government subsidizes a new technology, the large firms that control the market respond by allocating large funds to their own research and development programs. Overall, more research is focused on that technology than before subsidization started, which can lead to significant technological improvements. And, the more information large firms have about a promising "new" technology, the larger the chances that the technology in question will be adopted and promoted.

Although Arthur dismisses the idea of spending public money to support research related to new technologies on the grounds that it would produce minimum profit, he admits that significant technological advances cannot be made without research. Consequently, Arthur supports the adoption of policies that encourage individual firms to invest in research and development, and to promote aggressive searches for product and process improvements. In particular, such policies should favor joint ventures that pool together the resources of many firms, thus allowing them to share up-front costs, marketing networks, technical knowledge and standards. At the international level, such policies should promote strategic alliances that enable companies in several countries to penetrate complex industries together, action that no company could sustain by itself. But even if adequate policies can favor the development of a technology, Arthur warns, its success or failure is dictated by one factor: timing. To have a fair chance to succeed, a firm or technology should enter a market only if it is not locked-in.

6.3.2 Application to cooling technologies

In the specific case of cooling technologies, Feustel and collaborators [2] call for significant policy interventions to allow alternative technologies to gain a share of the air-conditioning market. They state that such policy interventions are justified by the fact that not all the cost of compressor-driven air-conditioning is borne by the consumers. The costs imposed on utilities to support the capacity necessary to meet air-conditioning demand ("the load from hell" [4]) are borne by all utility ratepayers, while the costs of increased emissions from electricity production and of chlorofluorocarbon (CFC) use for air-conditioning are borne globally. Feustel and collaborators show that to be successful, policies supporting alternative technologies must be based on information regarding the environmental aspects of cooling, as well as end-user behavior.[1] It is worthwhile mentioning, however, that deep understanding of the environmental and behavioral issues associated with space cooling may not necessarily produce arguments for the promotion of alternative cooling technologies. Considering the large, reliable infrastructure that supports the compressor-driven technology, small improvements that remedy the environmental- and end-user problems currently attributed to this technology may prove to be more attractive than the adoption of alternative technologies.

Environmental issues

The externalities arising from the use of compressor-driven air-conditioning have been thoroughly studied and documented. The same cannot be stated about alternative technologies: there is practically no information showing whether the use of alternative technologies is associated with any negative impacts. Theoretically, the net environmental impacts should be positive because alternative technologies reduce energy consumption and limit CFC use. However, to provide real support to policy formulation, any negative impacts must be identified, studied, and documented. Then the social costs of all externalities associated with all technologies should be catalogued and quantified where possible. This would help identify the most effective improvements in each existing technology, and would allow the formulation of policies that support the most beneficial technology.

Behavioral issues

Consumer behavior. Consumer preference for one technology over another should represent the central concern of those involved in formulating policies. At present, consumers perceive the compressor-driven technology as convenient, reliable, and relatively inexpensive. Furthermore, their expectations regarding the performance of a cooling system are based on their experience with the compressor-driven technology. Understanding the extent to which people are willing to part with the familiar compressor-driven technology in exchange for the lower operating costs and environmental benefits of alternative technologies is crucial for determining whether these technologies would be accepted, and which technology would be accepted more easily. In addition, studies focused on identifying those segments of the population where individual motives such as commitment to energy efficiency, or the desire to prevent further pollution of the environment, are prevalent could reveal market niches where alternative cooling technologies would be readily accepted. Studies focused on identifying those segments of the population where individual motives such as reluctance to become a ground-breaking individual, or resistance to invest in an unfamiliar technology are prevalent could

1. Arthur [1] overlooked this aspect of policy adoption: successful policies must be based on reliable information. It is debatable whether this type of subsidization produces any immediate profits.

reveal the sectors of the market where the adoption of alternative technologies should be encouraged through financial incentives.

Moreover, policy formulation should be supported by examples of implementation. Experience shows that public awareness and acceptance of a new technology is usually contingent upon the existence of a few “success stories” to which individuals (and institutions) can relate. In the specific case of radiant cooling, the achievement of pilot projects that include radiant cooling systems in the design of a few high-profile buildings would provide the necessary proof-of-concept, as well as a benchmark for the performance of these systems. Setting the pilot projects in hot- or warm-humid climates would demonstrate the ability of radiant cooling systems to condition even buildings located in extreme climates. Joint US Department of Energy, industry, and utility sponsorship of such pilot projects would help direct public attention towards the different benefits of adopting radiant cooling systems.

Behavior in the building profession. Because they are in a position to decide what technologies to incorporate into their design, architects and engineers constitute a crucial connection between innovation and implementation. However, these building practitioners are not *required* to promote “new” technologies; in fact, they are unlikely to promote a new technology if they perceive that some of its attributes detract them from their goals [5]. In addition, traditional construction methods are deeply embedded, and generally hard to overcome. Consequently, policies promoting a given technology should take into consideration the mechanisms that underlie the decision-making processes in the design activity, and the extent to which the interaction between the different types of professionals in the building community may help or hinder the adoption of the technology in question. In the case of radiant cooling, system particularities call for close cooperation among the building practitioners during the design process. The existence of an upper limit for the cooling load that a radiant cooling system can remove from a building requires the architect and the HVAC engineer to join forces in the design of the building and its cooling system. Considering the extent and the nature of the current interactions between these two types of building practitioners [6], such teamwork may be difficult if not altogether impossible to instill in the absence of special incentives.

6.3.3 Other measures

Because alternative cooling technologies in general, and radiant cooling in particular, must overcome the lack of familiarity and experience, a variety of other measures may be necessary to encourage their market adoption. The measures that Feustel and collaborators [2] propose are incentives, standards, and education programs. This section will discuss the nature of these measures, and the ways in which their adoption would influence the promotion of radiant cooling by the air-conditioning industry. It is worthwhile mentioning that education, incentives and standards are measures that support each other, therefore they should be implemented simultaneously.

Education. Education in the spirit of energy conservation should be directed both towards the public, which generates the demand for a product or technology, and towards the building profession, which is instrumental in adopting an energy efficient technology. In the specific case of alternative cooling technologies, information about functioning principles and energy-related benefits must be added to the general education promoting energy efficiency. Experience shows that, when promoting radiant cooling, the most frequently asked questions by individuals from the public and the building profession alike are:

(1) what is radiant cooling?

(2) how fast do the water pipes start to leak, and what are the consequences of a leaky

system?

(3) how do you dispose of the condensation that forms on the cold surface?

These questions demonstrate that, for the most part, North Americans are oblivious to the *existence* of radiant cooling systems. As radiant cooling systems differ from traditional all-air systems more than other alternative technologies, their functioning principle must be explained in detail before any information about their benefits can be understood by the public. Moreover, after an explanation has been offered regarding the principles of radiant cooling, further effort is necessary to overcome the public's preconceptions. Experience with leaky water pipes leads the public to expect that all water pipes will leak sooner or later. Everyday exposure to window condensation naturally brings the assumption that condensation will form on any cold surface. To effectively raise public awareness about radiant cooling systems, these issues must be addressed. It is obvious that the existence of a few pilot projects incorporating the technology would be instrumental in the education process. Buildings equipped with radiant cooling systems would allow individuals to *feel* the cooling effect produced by these systems, and would demonstrate that, when in operation, they neither leak nor "sweat".

The information passed on to the building professionals should clearly be more specific and detailed. To elicit the interest of architects and engineers, these building professionals must be informed in detail about the functioning principle of radiant cooling systems, the energy-related advantages associated with installing such systems in buildings, and the changes that building practices must undergo to support proper installation and operation of radiant cooling systems. Since no building simulation program has thus far been able to model the performance of buildings equipped with radiant cooling systems, the few architects and engineers who may have been aware of the potential benefits of employing radiant cooling systems have not had access to any tool able to verify the soundness of a design incorporating such a system, or its potential to save energy. Its limitations and shortcomings notwithstanding, RADCOOL creation represents a necessary step towards a better understanding of the radiant cooling concept within the building profession. The proposed incorporation of RADCOOL into DOE-2 would facilitate program improvement, while simultaneously allowing the members of the building community to access this calculation tool through the familiar DOE-2 environment.

Incentives. Informing the public and the building profession about the benefits of a “new” technology does little to encourage the adoption of the technology without the support of financial incentives. Recognizing that the main obstacle in the accomplishment of energy conservation projects is the up front cost required from the end-user to install energy efficient measures, most utilities sponsor demand-side management (DSM) programs. These programs diminish, or even eliminate the up front cost associated with the energy efficiency project, and often offer free installation of measures. The education that the end-user inherently receives when agreeing to participate in such a project is probably more valuable than the information that the market provides regarding a given energy efficient technology or measure. Behavioral changes may also be initiated while carrying out such projects, although it is unclear whether the effects of education through personal contact persist, and for how long.

If offered appropriate financial incentives, architects and engineers could also become interested in including alternative cooling technologies in their design. At present, engineering fees are based on a percentage of the capital cost of the project, subcontract, or equipment installed, not on the energy savings achieved by a particular system design. Since many of the alternative cooling technologies employ smaller-size equipment (ducts, fans, chillers, etc.) when compared to the traditional all-air systems relying on compressor-based chillers, including such systems in building design would reduce the building practitioners’ fees. Acknowledging this difficult position, energy saving performance contracts (ESPCs) and performance-based architect and engineer (A/E) compensation programs offer financial means for shifting the designers’ incentives towards energy efficiency.

Currently, energy saving performance contracts are almost exclusively used in retrofit situations. At the request of a building owner, an energy service company analyzes the building and identifies different sets of energy efficient measures that could reduce building energy consumption. After a set of measures has been selected, a third party finances the proposed energy conservation measures and their implementation, under the agreement that a share of the savings achieved will be dedicated to repaying the cost of the project. Since compensation to the energy service company provider is based on shared savings defined over some period of time, it is in this company’s interest to identify the most beneficial energy efficiency measures, and to provide quality work for their installation.

The performance-based A/E compensation programs use the performance of a new building as built to encourage energy efficient design by granting monetary rewards, and to discourage substandard energy performance by exacting penalties. The “feebate” program currently in progress in Oakland, California [7] is set to reward the building designers for efforts that bring value in the form of energy savings to the owner, while compensating the owner for having to pay higher energy bills in the case of a poorly performing building. In the “feebate” program, compensation to the A/E firm is conceived as a one-time payment depending on the achieved savings, and is delivered a few years after project completion.

There are two main caveats to the energy conservation projects described above. First, even when the incentives offered to building designers (compensation based on savings) to produce energy efficient design, specific performance standards do not exist to ensure that, once built, the building performs as promised. Second, because traditional design and construction methods are deeply embedded in the building profession, participation in a performance-based A/E compensation program does not necessarily encourage building professionals to implement energy efficiency measures in future designs. This shows the importance of adopting building standards that institutionalize energy efficient building practices.

Standards. Recognizing the importance of energy conservation for building a sustainable economy, the Swiss government called for new building standards in the late 1980s. The canton of Zürich subsequently implemented a new energy law (Vollzugsordner Energie 1989 [8]) that imposes a set of design measures requiring the architect-engineer team to minimize both weather-induced and internal loads in building design. Some of these measures are: a prescribed minimum insulation level, the use of architectural shading and of glazing with a low heat transmission coefficient, the use of efficient hot water systems, a prescribed minimum value for the efficiency of heat recovery systems. After the building design has been completed and compliance with the standard has been verified, the building design team must model the indoor conditions that would be obtained inside the building in the absence of mechanical cooling. If load calculations show that indoor conditions would be uncomfortable, and that indoor comfort cannot be achieved through the implementation of additional architectural measures, the building owner is eligible to apply for a permit to install mechanical cooling in the building. Even if such a permit is granted, the local government often limits the use of compressor cooling to night time hours. Under these circumstances, the capability of core cooling radiant systems to create comfortable indoor conditions during occupancy hours by pre-cooling a building during night time hours, combined with their relatively low electricity demand, have led to their current large-scale implementation in new construction in Switzerland.

The provisions of the energy laws recently implemented throughout Switzerland offer a partial explanation for the current interest in the implementation of energy efficient measures and technologies in building construction in that country. It is obvious that a similar result cannot be obtained in the US without a serious re-examination of current building standards. To this end, issues such as the relevance of the comfort zone (described by ASHRAE Standard 55-1989 [9]), the ideal of maintaining a constant temperature indoors, and the practice of using electricity-driven chillers to provide cooling, should come under close scrutiny.

It is worthwhile mentioning, however, that this type of action may or may not be beneficial from the point of view of alternative cooling systems in general, and of radiant cooling systems in particular. Reformulating the “expected norms” may loosen the requirements imposed on the operation of HVAC systems, thus reducing the “opportunity for savings” for alternative cooling systems. Imposing the generalized use of alternative cooling sources (cooling towers, ground coupling, thermal storage) may lead to traditional all-air systems that are more energy efficient than alternative cooling systems. A tightening of the building standards may call for building design that eliminates the need for air-conditioning altogether. In addition, the lack of an infrastructure, and the need to train building practitioners in the design and installation of radiant cooling systems, may render the promotion of these systems (even when combined with other energy efficient measures) economically unattractive.

6.4 Conclusion

This thesis has shown that radiant cooling systems create comfortable indoor conditions, have high potential to reduce building energy consumption and peak power demand, are economically competitive, and are not restricted to specific geographic areas in the United States. So far, market control by the compressor-driven technology, preconceptions of the public, and the difficulty of overcoming traditional building practices have been serious barriers to the adoption of radiant cooling in the United States. These barriers cannot be overcome without serious commitment to reducing the externalities that arise from the use of the compressor-driven technology. Commitment at government or public level translates into policy formulation, building standards, building practices, and, in time, into individual behavior and expectations. The Swiss example demonstrates the opportunities opened to alternative cooling technologies by government commitment to energy efficiency. In the United States, efforts to promote energy efficiency have so far been visible only at the level of the environmental community. The future will show whether government or public commitment to energy efficiency can be achieved in the United States, and whether market access will thus be opened to alternative cooling technologies in general, and to radiant cooling in particular.

6.5 References

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